

MODERN VIEWS OF ELECTRICITY.¹

PART I.

II.

FIRST you have an inextensible endless cord circulating over pulleys; this is to represent electricity flowing in a closed circuit. Electromotive forces are forces capable of moving the cord, and you may consider them applied either by a winch, or by a weight on the hook *w*. A battery cell corresponds to a small weight; an electric machine to a slow but powerful winch. Clamping the cord with the screw *s* corresponds to making the resistance of the circuit infinite. Instead of the cord, clamp, and driving

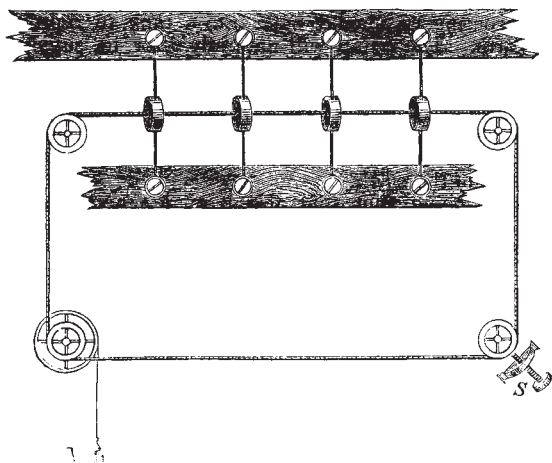


FIG. 5.—Mechanical analogy of a metallic circuit.

pulley, one might consider an endless pipe full of liquid with a stop-cock and a pump on it, but for many purposes the cord is sufficient and more simple. In Fig. 5, the only resistance to the motion is friction, and there is no tendency to spring back. Fixed beads are shown on the cord to typify atoms of matter, and they may be more or less rough to represent different specific resistances. If the cord be moved, heat is the only result.

Now pass to Fig. 6. Here the cord is the same as before

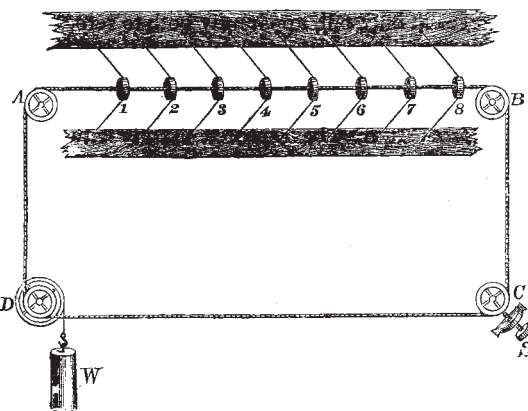


FIG. 6.—Mechanical analogy of a circuit partly dielectric: for instance, of a charged condenser. A is its positive coat, B its negative.

but the beads are firmly attached to it, so that if it moves they must move with it. They represent, therefore, the particles of an insulating substance. Nevertheless, their

supports are not rigid—they do not prevent the cord moving at all; they allow what is called electric “displacement,” not conduction; they can be displaced a little from their natural position, but they spring back again when the disturbing E.M.F. is removed. The beads in this figure are supposed to be supported by elastic threads: if the cord were replaced by a closed pipe full of water they would be replaced by elastic partitions.

Apply a given E.M.F. to this cord and a definite displacement is produced. One side gets more cord than usual—it is positively charged; the other gets less—it is negatively charged. If the applied E.M.F. exceeds a certain limit the strain is too great. The elastics break, and you have disruptive discharge with a spark. But even when the strain is only moderate some of the supports may yield viscously, or be imperfectly elastic and permit a gradual extra displacement of the cord, known to telegraphists as “soaking in.”

When discharge is now allowed, it will not at once be complete; a large portion of the displacement will be at once recovered, but the rest will gradually “soak out” and cause residual discharges.

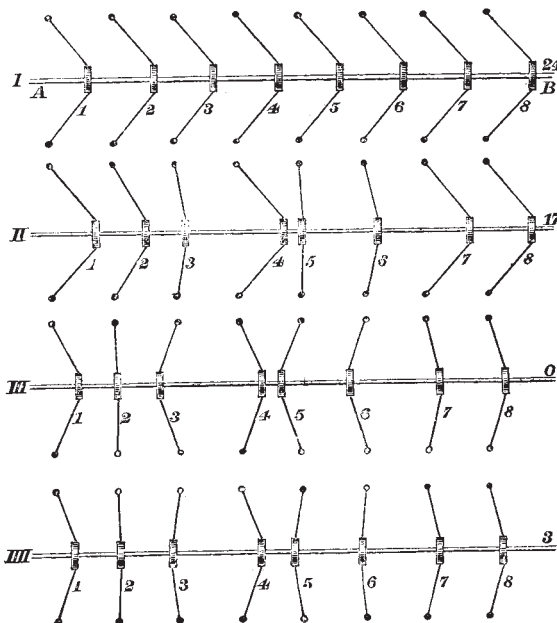


FIG. 7.—Stages in the discharge of a stratified condenser; showing one way in which the phenomena of “residual charge,” “internal charge,” and “soaking out” are produced.

If the dielectric is at all stratified in structure, so that some of the beads allow cord to slip through them—or yield more than others—then this residual charge effect will become very prominent.

Fig. 7 illustrates the various stages of a stratified dielectric, with layers of imperfect insulating power. I. represents a recent charge, of E.M.F. 24. II. represents the same after lapse of time, reduced to 17 by partial internal leakage; and shows internal charge. The circuit itself is supposed to have been perfectly insulating all the time. III. shows the first discharge; and IV. shows the state attained after again waiting, viz. a residual charge with an E.M.F. 3 in the old direction.

Return, however, to the simple discharge, and see how it occurs. Will it take place as a simple sliding back of the beads to their old position? Yes, if the resistance of the circuit is great, but not otherwise. If the cord is fairly free the beads will fly past their mean position, overshooting their mark, then rebound, and so, after many quick oscillations, will finally settle down in their

¹ Expansion of a lecture delivered by Dr. Oliver Lodge, partly at the London Institution on January 1, 1885, and partly at the Midland Institute, Birmingham, November 15, 1886, but not hitherto published. Continued from p. 536.

natural position. Thus is represented the fact that the discharge of a Leyden jar is in general oscillatory; the apparently single and momentary spark, when analyzed in a very rapidly rotating mirror, turning out to really consist of a series of alternating flashes rapidly succeeding one another, and all over in the hundred-thousandth of a second or thereabouts. These oscillatory currents were predicted and calculated beforehand by Sir William Thomson; they were first observed experimentally by Feddersen. The oscillations continue until the energy stored up in the strained medium has all rubbed itself down into heat.

Fig. 8 shows part of an actual model of the kind.

To make the model represent *charge by induction* all that has to be done is to immerse a conductor into the polarized dielectric—in other words, to make one or more

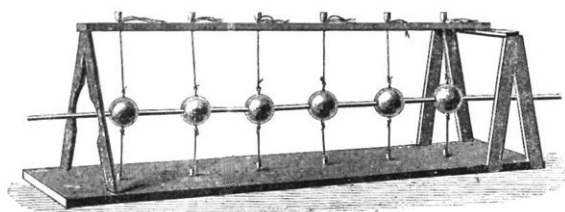


FIG. 8.—Partial model of a dielectric.

of the beads of the fixed and slippery conducting kind, the other beads on the cord being of the elastic and adhesive or insulating kind. Then when the displacement occurs it is plain that a deficiency of cord will exist on one side of the metallic layer and a surplus on the other, as shown in Fig. 9. This state of things corresponds exactly to the equal opposite induced charges on a conductor under induction, as in Fig. 3. If the strain on one side be relieved by letting the beads on that side slip back on the cord: that corresponds to touching the conductor to earth, as in Fig. 4. The other side has now to withstand the whole E.M.F., consequently the strain there and the charge there will have increased. Remove now the applied E.M.F., and the negative charge appears on both sides of the metal partition, either equally, or more markedly on that side which has fewest beads, *i.e.* which is nearest to other conductors.

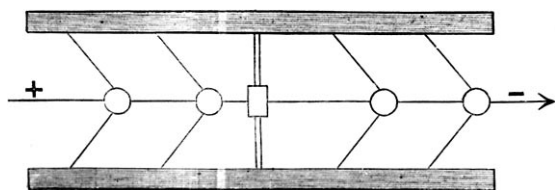


FIG. 9.—Metallic layer in the midst of a polarized dielectric, showing opposite charges "induced" on its surfaces. (Compare Fig. 3.)

Hydraulic Model of a Leyden Jar.—So much for the cord model, but I will now describe and explain an hydraulic model which illustrates the same sort of facts: some of them more plainly and directly than the cord model. Moreover, since all charging is essentially analogous to that of a Leyden jar, let us take a Leyden jar and make its hydrostatic analogue at once.

The form of jar most convenient to think of is one supported horizontally on an insulating stand, with pith ball electroscopes supplied to both inner and outer coatings.

To construct its hydraulic model, procure a thin india-rubber bag, such as are distended with gas at toy-shops; tie it over the mouth of a tube with a stop-cock, A, and insert the tube by means of a cork into a three-necked globular glass vessel or "receiver," as shown in the diagram, Fig. 10.

One of the other openings is to have another stop-cock tube, B; and the third opening is to be plugged with a cork as soon as the whole vessel, both inside and outside the bag, is completely full of water without air-bubbles.

This is the insulated Leyden jar: the bag represents the dielectric, and its inner and outer coatings are the spaces full of water.

Open gauge-tubes, *a* and *b*, must now be inserted in tubes A and B, to correspond to the electroscopes supplied to the jar; and a third bent tube, C, connecting the inner and outer coatings, will correspond to a discharger. Ordinarily, however, of course C will be shut.

A water-pump screwed on to A will represent an electric machine connected to inner coating; and the outer coating, B, should open into a tank, to represent the earth. The pump will naturally draw its supply of water from the same tank.

The bag being undistended, and the whole filled with water free from air, the level of the water in the two gauge-tubes will correspond with that in the tank; and this means that everything is at zero potential, *i.e.* the potential of the earth.

Now, C being shut, shut also B, open A, and work the pump. Instantly the level in the two gauges rises greatly and equally: you are trying to charge an insulated jar. Turn an electric machine connected to a real jar, and its two pith balls will similarly and equally rise.

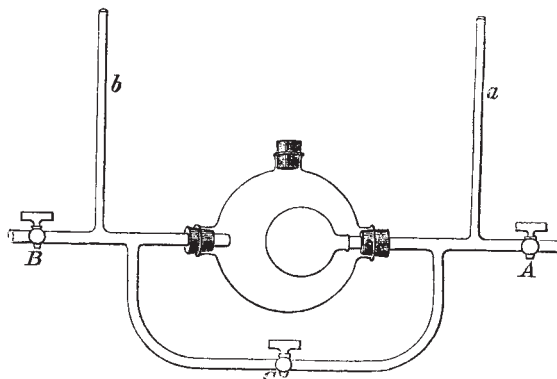


FIG. 10.—Skeleton diagram of hydraulic model of a Leyden jar.

Now open B for an instant, the pressure is relieved, and both gauges at once fall, apparently both to zero. Repeat the whole operation several times however, and it will be found that whereas *b* always falls to zero, *a* falls short of zero each time by a larger amount, and the bag is gradually becoming distended. This is *charge by alternate contact*. It may be repeated exactly with the real jar: a spark put in to the inner coating, and an equal spark withdrawn from the outer coating each time; and unless this outer spark is so withdrawn, the jar declines to charge: water (and electricity) being incompressible.

If B is left permanently open, the pump can be steadily worked, so as to distend the bag and raise the gauge *a* to its full height, *b* remaining at zero all the time, save for oscillatory disturbances.

Having got the jar charged, shut A, and remove the pump, connecting the end of A with the tank directly.

Now of course by the use of the discharger C the fluid can be transferred from inner to outer coat, the strain relieved, and the gauges equalized. But if this operation be performed while the jar is insulated, *i.e.* while A and B are both shut, the common level of the gauges after discharge is not zero, but a half-way level; and the effect of this is very noticeable if you touch an insulated Leyden jar after it has been discharged.

Instead of using the discharger C, however, we can proceed to discharge by alternate contact, and the operation is very instructive.

Start with the gauge *b* at zero, and the gauge *a* at high pressure. Open stop cock A; some water is squeezed out of inner coating, and the *a* gauge falls to zero, but the suck of the contracting bag on the outer coat pulls down

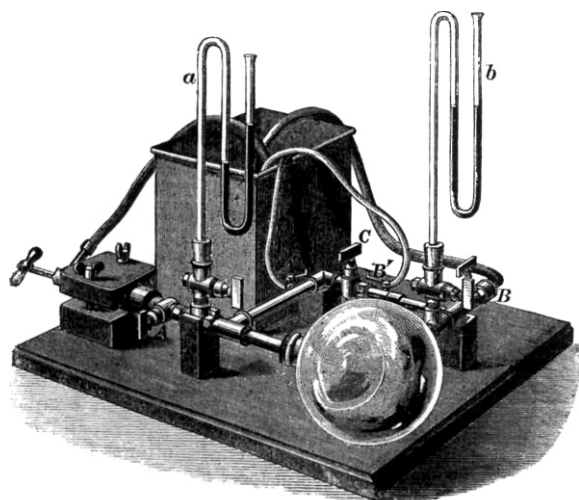


FIG. 11.—First actually constructed model Leyden jar, with mercury gauges for electrometers; the whole rigged up with things purchasable at a plumber's, except the pump.

the gauge *b* below zero, the descent of the two gauges being nearly equal.

Next shut A and open B; a little water flows in from

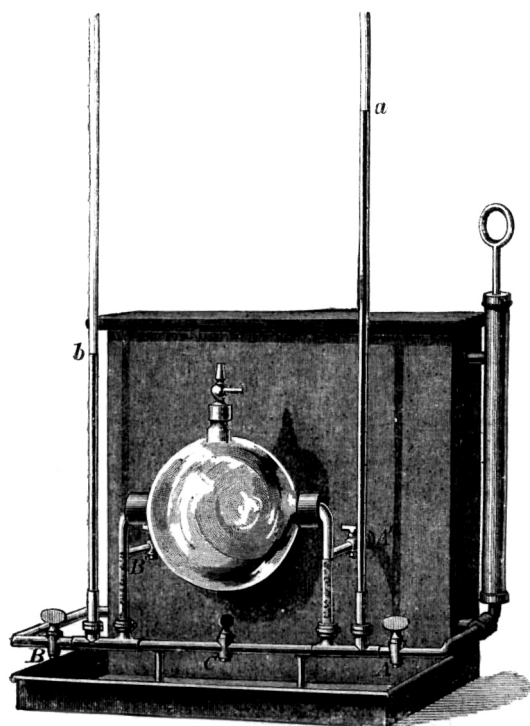


FIG. 12.—Latest form of hydraulic model of a Leyden jar with water gauges, the whole arranged vertically to be more conspicuous. The pump is a force-pump with a communication between top of barrel and tank to get rid of stray water.

the tank to still further relieve the strain of the bag, and both gauges rise; *b* to zero, *a* to something just short of its old position.

Now shut B and open A again: again the two gauges descend. Reverse the taps, and again they both rise; and so on until the bag has recovered its normal size. This is discharge by alternate contact, and exactly imitates the behaviour of an insulated charged Leyden jar whose inner and outer coats are alternately touched to earth. Its pith balls alternately rise with positive and with negative electricity, indicating potentials above and below zero.

Figs. 11 and 12 are taken from photographs of apparatus I have made to use as just described. The glass globe with the partially distended bag inside it, the pump, the tank, the gauges *a* and *b*, the stop-cocks A B C, will be easily recognized. Two extra stop-cocks, A' and B', leading direct to tank, are extra, and are to save having to disconnect pump and connect A direct, when exhibiting the effect of "discharge by alternate contact." But the tank is not sufficiently tall in Fig. 12; I have doubled its height since. The full height of the gauge-tubes is barely shown.

In any form of apparatus it is essential to fill the whole with water—pipes, globe, everything—before commencing to draw any moral from its behaviour. It is rather difficult to get rid of a large bubble of air from the top of the globe of Fig. 11, and though it is not of very much consequence in this place, the stop-cock in Fig. 12 is added to make its removal easy. The gauges in Fig. 11 may be replaced by others arranged as a lantern-slide, and connected by flexible tubing full of air.

I have explained thus fully the hydraulic illustration of Leyden jar phenomena, because these constitute the key to a great part of electrostatics. The illustration is not indeed a complete or perfect one by any means, but by combining with it a consideration of the endless cord models, and of what I have endeavoured to explain concerning conduction and insulation in general, a distinct step may be gained.

Think of electrical phenomena as produced by an all-permeating liquid embedded in a jelly; think of conductors as holes and pipes in this jelly, of an electrical machine as a pump, of charge as excess or defect, of attraction as due to strain, of discharge as bursting, of the discharge of a Leyden jar as a springing back or recoil oscillating till its energy has gone.

By thus thinking you will get a more real grasp of the subject and insight into the actual processes occurring in Nature—unknown though these may still strictly be—than if you employed the old ideas of action at a distance, or contented yourselves with no theory at all on which to link the facts. You will have made a step in the direction of the truth, but I must beg you to understand that it is only a step, that what modifications and additions will have to be made to it before it becomes a complete theory of electricity I am wholly unable to tell you. I am convinced they will be many, but I am also convinced that it is unwise to drift along among a host of complicated phenomena without guide other than that afforded by hard and rigid mathematical equations.

The mathematical theory of potential and the like has insured safe and certain progress, and enables mathematicians to dispense for the time being with theories of electricity and with mental imagery. Few, however, are the minds strong enough thus to dispense with all but the most formal and severe of mental aids: and none, I believe, to whom some mental picture of the actual processes would not be a help if it were safely available.

Such a representation I have endeavoured partially to lay before you to-night, and I hope, if I have succeeded in making myself at all intelligible, that those students of electricity who may be present will find it of some use and service.

O. J. LODGE.

(To be continued.)